PREPARATION OF SYNTHETIC COMPOSTS FOR MUSHROOM CULTURE[1]

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(WITH TWO FIGURES)

Introduction

Horse manure and its straw bedding is the standard medium in commercial mushroom culture today. Since horse manure has become scarce and increasingly costly in our automobile age, attempts have been made to find substitutes during the past twelve years. In order to produce an economical and competitive "artificial manure" or "synthetic compost" it is necessary to use other wastes, especially industrial and agricultural by-products. The method of preparing synthetic composts described in this paper has been tested over a period of five years; several thousand tons have been prepared, and the yield has been as good as or better than that from horse manure composts.

The history of "artificial manures" began in 1923 when RICHARDS and HUTCHINSON (**5**) patented a method for preparing "nitrogen fertilizers" from straw and inorganic nitrogen. In a later patent (**6**) phosphates also were included. The gist of their method is that 3.6 lb. of nitrogen, preferably in a soluble form, should be added to 500 lb. of straw; larger quantities of nitrogen produced a high alkalinity which checked the decomposition of the straw and caused a loss of nitrogen. In 1930, LAMBERT (**3**) and HEIN (**2**) attempted to use this method for preparing a compost for mushroom culture. The yield of mushrooms they obtained from such composts was less than one-half of the yield from horse manure composts. Their investigation demonstrated that normal mushrooms could be produced from an artificial manure even though the yield was unsatisfactory.

Later WAKSMAN and RENEGER (**15**) prepared synthetic composts by adding alfalfa and ammonium phosphate to straw. Their aim in this use of alfalfa was to facilitate the decomposition of the straw by adding to it a "green material" with a high moisture content. The yield of this compost was 70 per cent. of that of a manure compost. They also prepared composts of tobacco stems and straw; the yields of these were variable.

Recently SINDEN (**7**) prepared synthetic composts consisting of wheat straw, urea, and wheat. Urea was selected as a source of nitrogen in preference to other compounds because it left "no inorganic residue." The wheat was added to help retain the heating capacity of the compost. The best yields he obtained with such composts were about two-thirds of the yields with manure composts, per square foot of bed surface.

This brief review of the attempts to prepare synthetic composts for mushroom culture shows that only nitrogen has been considered significant, so

[1] This paper is a contribution of the L. F. Lambert Research Laboratory, Coatesville, Pennsylvania.

that the composts prepared by these investigators are essentially the same as the "nitrogen fertilizer" of Richards and Hutchinson. Comparatively slight attention has been given to the need for phosphates and no attempt has been made to observe the necessity for potassium salts. The composts of these investigators refer only to specific mixtures; no means are provided whereby materials other than those specifically mentioned might be substituted. Thus it would be hazardous to deviate from any specific combination since the function of each constituent used is not fully understood. While these investigators have increased our knowledge of synthetic composts, they have not developed a compost which will consistently produce a yield of mushrooms equal to or greater than that produced by a compost of horse manure and its straw bedding.

Basis of present method

The basis for the method of preparing synthetic composts in the present investigation was to analyze both the medium (horse manure) and the product (the mushroom) for their chief chemical constituents, and then seek

TABLE I

AN AVERAGE ANALYSIS OF HORSE MANURE AND ITS STRAW BEDDING

MINERAL CONSTITUENTS	PERCENTAGE, DRY BASIS	AMOUNT IN ONE TON (70% MOISTURE)
	%	*lb.*
N	2.0	12.0
P_2O_5	1.0	6.0
K_2O	2.7	16.0

to produce synthetically a medium which would contain these significant constituents. The composition of horse manure is variable. When numerous samples have been analyzed, however, and when the analyses are compared with those of other investigators, a workable average may be obtained as shown in table I. The analysis of the ash and organic matter of the mushroom is shown in table II. These analyses show that nitrogen, phosphorus, and potassium are present in significant quantities in both the medium and the product, and must all be used in preparing synthetic composts.

As a result of extensive experimentation, it has been found that a ton of synthetic compost with 70 per cent. moisture should contain about 13 lb. N, 4 lb. P_2O_5, and 10 lb. K_2O. It would seem, then, that manure contains more P_2O_5 and K_2O but less N than is necessary to produce the largest yield of mushrooms. The writer believes the reason for artificial manure, in which only the nitrogen factor has been given due consideration, yielding normally "when mixed half and half with composted horse manure" (**4**), is because superfluous quantities of P_2O_5 and K_2O are present in the manure. The ratio of N to P_2O_5 to K_2O found in the mushrooms (6.4 : 2.4 : 4.4) appears to be about the same as has been found satisfactory for preparing synthetic composts. This analysis of the mushroom may, however, reflect

TABLE II

AN ANALYSIS OF THE ASH AND ORGANIC MATTER OF THE MUSHROOM (SPOROPHORE), *Agaricus campestris*

MINERAL CONSTITUENTS OF ASH (1)	PERCENTAGE	ORGANIC CONSTITUENTS OF DRY MATERIAL (13)	PERCENTAGE
	%		%
K_2O	43.94	Ether-soluble portion	5.14
Na_2O	2.31	Hot water-soluble organic matter	42.16
CaO	1.32	Alcohol-soluble portion	7.02
MgO	0.21	Hemicelluloses	13.66
Fe_2O_3	0.24	Cellulose	4.86
Mn_2O_3	0.02	Lignin	0.92
Al_2O_3	2.31	Protein	40.35
P_2O_5	24.25	Nitrogen	6.44
SiO_2	8.23		
Cl	9.22		
SO_3	3.01		

only the specific condition of these constituents in the particular manure on which the mushrooms grew.

The procedure in accordance with the method (**10**) herein described is to analyze the materials to be used in preparing the synthetic composts into their N, P_2O_5, and K_2O constituents as shown in table III. The straw and root composts are equivalent to a ton of manure with 70 per cent. moisture. In the computation of these composts, the N, P_2O_5, and K_2O in the fibrous material is considered first; any deficiencies of these constituents are then supplied from various sources. The number of sources is immaterial as long

TABLE III

TABULATION OF THE CONSTITUENTS OF SYNTHETIC COMPOSTS

MATERIALS	QUANTITY	N	P_2O_5	K_2O
LICORICE ROOT COMPOST				
	lb.	*lb.*	*lb.*	*lb.*
Spent licorice roots (67.5% moisture)	2000.0	6.5	1.0	......
Dried brewers' grains	180.0	7.4	1.8	......
Sulphate of potash (50% K_2O)	18.0	......	......	9.0
Muriate of potash (50% K_2O)	3.0	......	......	1.5
Superphosphate (20% P_2O_5)	7.5	......	1.5	......
Hydrated lime [94% $Ca(OH)_2$]	6.0	......	......	......
Totals	......	13.9	4.3	10.5
STRAW COMPOST				
Rye straw	500.0	2.5	1.0	5.0
Wet brewers' grains	660.0	7.0	1.6	......
Uramon (42% N as urea)	8.3	3.5	......	......
Superphosphate (20% P_2O_5)	10.0	......	2.0	......
Sulphate of potash (50% K_2O)	9.0	......	......	4.5
Muriate of potash (50% K_2O)	3.0	......	......	1.5
Hydrated lime [94% $Ca(OH)_2$]	9.0	......	......	......
Totals	......	13.0	4.6	11.0

TABLE IV

THE PREPARATION OF SYNTHETIC COMPOSTS WITH SPENT LICORICE ROOTS AND VARIOUS SOURCES OF NITROGEN. THE RATIO OF $N:P_2O_5:K_2O$ IS ON THE AVERAGE: 15:5:10. SUPERPHOSPHATE (20% P_2O_5) AND SULPHATE OR MURIATE OF POTASH (50% K_2O) ARE USED TO SUPPLEMENT ANY DEFICIENCIES OF PHOSPHORUS AND POTASSIUM IN THE ROOTS AND SOURCES OF NITROGEN TO ATTAIN THIS RATIO

PLOT	SOURCES OF NITROGEN	ADDED PER TON OF ROOTS	NITROGEN PER TON OF ROOTS	SIZE OF PLOT	MUSHROOMS PER PLOT	MUSHROOMS PER SQ. FT.	COMMERCIAL YIELD* PER SQ. FT.
		lb.	*lb.*	*sq. ft.*	*lb.*	*lb.*	*lb.*
38	Dried blood	60.0	7.8	48	111	2.31	1.73
40	Cottonseed meal	120.0	8.0	48	113	2.35	1.77
41	Soybean meal	123.0	8.0	48	141	2.94	2.20
42	Castor bean meal	145.5	8.0	48	129	2.69	2.02
43	Malt sprouts	189.5	8.0	48	164	3.42	2.56
46	Beet molasses	200.0	2.8	48	92	1.92	1.44
	Ammophos	20.0	3.2				
	Urea	4.4	2.0				
47	Tobacco stems (ground)	150.0	3.8	48	97	2.02	1.52
	Urea	10.0	4.5				
48	Cottonseed meal	40.0	2.7	48	129	2.69	2.02
	Dried blood	20.0	2.6				
	Urea	5.5	2.7				
49	Dried blood	7.7	1.0	24	64	2.67	2.00
	Cottonseed meal	15.0	1.0				
	Soybean meal	15.4	1.0				
	Dried brewers' grains	23.4	1.0				
	Dried yeast	2.5	0.2				
	Urea	8.6	4.0				
49A	Same as 49	....	.....	24	61	2.54	1.91
51	Dried tannery sludge	200.0	4.0	48	119	2.48	1.86
	Urea	8.6	4.0				
52	Same as 51 plus "Ultra-Life" —(Vitamin feed conc.)	10.0	.....	48	131	2.73	2.05
53	"Uramon" (urea with 42% N)	20.4	8.5	24	27	1.13	0.84
53A	Same as 53 plus 2 lb. more lime	....	.....	24	47	1.96	1.47
54	"Uramon"	22.8	9.5	48	143	2.98	2.24
	Chopped straw	75.0					
	Cheese whey	10.0					
55	Calcium nitrate	63.5	9.5	48	136	2.83	2.13
58	Ammonium sulphate	42.5	8.5	48	None	....	....
59	Ammonium sulphate	47.5	9.5	24	59	2.46	1.84
	Chopped corn cobs	100.0					
	Cheese whey	10.0					
59A	Same as 59 plus 2 lb. more lime	....	.....	24	39	1.63	1.22
60	Dried brewers' grains	200.0	8.2	48	151	3.15	2.36
66	Same as 60 plus different source of potash	200.0	8.2	48	148	3.08	2.31
70	Dried brewers' grains	100.0	4.1	24	71	2.96	2.22
	Urea	9.2	4.2				
75	Dried brewers' grains	100.0	4.1	48	157	3.27	2.45
	Dried blood	7.7	1.0				
	Cottonseed meal	15.0	1.0				
	Soybean meal	15.4	1.0				
	"Uramon"	4.8	2.0				

TABLE IV—(*Continued*)

PLOT	SOURCES OF NITROGEN	ADDED PER TON OF ROOTS	NITROGEN PER TON OF ROOTS	SIZE OF PLOT	MUSHROOMS PER PLOT	MUSHROOMS PER SQ. FT.	COMMERCIAL YIELD* PER SQ. FT.
76	Same as 75 plus 6 lb. more lime	....	.....	48	163	3.40	2.55
77	Same as 75 plus 6 lb. more of magnesium lime	....	.....	48	139	2.90	2.17
78	Extracted cocoa cake	200.0	6.0	48	147	3.06	2.30
	Urea	7.6	3.5				
79	Extracted cocoa cake	100.0	3.0	48	129	2.69	2.02
	Urea	13.0	6.0				

* Commercial yield: Since the mushrooms, as weighed for the cannery, included the stubs, a reduction of 25% is allowed, so as to conform with the weight of mushrooms cut for the market. The average weight of the stubs, with adhering soil, is 22% of the weight of the mushroom.

as they add up to the total quantities and ratio desired. Synthetic composts prepared from many different sources of N, P_2O_5, and K_2O gave equally good yields. This fact shows that these three constituents are available for the most part to the mushroom mycelium in the various sources investigated. The writer has observed large particles (of chemicals), which were very insoluble in water or in agar medium, oxidized by the growing mycelium.

In preparing the compost pile, the nitrogenous material is spread or sprayed over the surface of the widened heap of fibrous material and forked in about a foot. All mineral ingredients are then mixed together, diluted with an equal quantity of loam, and spread evenly over the top of the heap. The whole mass is then mixed, watered as it is turned, and arranged into a pile which will provide the necessary aeration.

This method of preparing composts by analyzing and tabulating the various materials affords a formulation in which various agricultural and industrial by-products may be substituted. In order to compete with a waste product like manure, the possibility for substitution is important; it is necessary to have a formula in which the least expensive by-products on the market may be used. This method also establishes a basis for the estimation of the quantity of a material required in a synthetic compost.

Materials for synthetic composts

Since the mushroom is a fungus, an organic source of carbon has to be supplied. Straw which has undergone a microbial decomposition is a satisfactory source. The straw also provides for the mushroom bed the fibrous structure which is necessary for the intensely aerobic growth of the mushroom mycelium. Fibrous materials like spent licorice roots (from which the licorice has been extracted) and spent tannery nuts, bark, and leaves (from which tannin has been extracted for industrial use) are even more satisfactory than straw. These materials already contain sufficient moisture, are suitably subdivided, and require only a short or no microbial decomposition.

The use of numerous nitrogen sources for synthetic composts is shown in table IV. Composts with some nitrogen sources gave better yields than with others. The yields, however, were affected by the composting period which, at 30 days, was rather long for these small plots; in a later consideration of the problem of composting it seemed that the yields of some of the plots would have been better if the composting period had been shorter.

Organic nitrogenous materials are preferable to inorganic because they serve also as a source of carbon, contain some K_2O and P_2O_5, and have a better heating capacity. A solution of inorganic nitrogenous substances absorbed in very finely ground straw or corn cobs, however, is a fair equivalent to the organic material. The selection of a suitable nitrogen source also depends, of course, on the cost of the material compared to the yield of mushrooms obtained by its use. The quality of the mushrooms produced by the use of any specific material is not superficially evident; possible intrinsic values are not commercially important at present.

Some organic nitrogenous materials may be unsatisfactory due to the presence of specific toxic constituents as in the case of cocoa shells and cake. These materials contain one per cent. or more theobromine which, at this concentration, prevents the growth of the mushroom mycelium. When the theobromine is extracted, however, as is the practice in the commercial manufacture of theobromine, the resulting extracted cocoa cake is a satisfactory source of nitrogen.

In the use of inorganic nitrogenous substances like ammonium salts, cyanamide, and urea special precautions are necessary; but nitrates may be used freely. Ammonia formed from the former substances persists in the compost (due to adsorption) even after the "sweating out process" and prevents the growth of the mushroom mycelium. One of the simplest methods for suppressing this excessive ammonification is to absorb solutions of the ammoniating substances in finely ground carbonaceous materials as already indicated; in this way the transformation of ammonia to microbial proteins is assisted; the use of an acidifying material like cheese whey is also helpful. If calcium cyanamide is improperly stored, that is, exposed to air so that it absorbs moisture and carbon dioxide, it is transformed to calcium dicyanodiamide. Composts prepared with dicyanodiamide even prevent the growth of the mushroom mycelium. In contrast to ammoniating salts, nitrates are not toxic to the mycelium. Nitrates are especially suitable for use with fibrous materials which do not undergo extensive microbial decomposition. Composts of nitrates with spent licorice roots or spent tannery bark require no outdoor composting.

The variety of sources of the other materials employed in the preparation of synthetic composts is comparatively limited. The best source of phosphates is superphosphate. Besides the fertilizer grades of potassium chloride and sulphate, the ash of various plant materials such as cottonseed hulls, and the ash of the sludge of alcohol distilleries may also be used. Current investigations, which will be reported at a future date, indicate that the "minor elements" are related to disease control. The addition to composts of yeast and vitamin concentrates failed to significantly increase the yield; the vitamin content of the mushroom, however, may have been increased.

TABLE V

THE EFFECT OF POTASH, PHOSPHATE, AND LIME ON THE YIELD OF MUSHROOMS WHEN ADDED TO A SYNTHETIC COMPOST CONSISTING OF SPENT LICORICE ROOTS AND BREWERS' GRAINS

Plot	Fertilizer salts per ton of compost				Mushrooms per 24 sq. ft.	Mushrooms per sq. ft.	Average
	K_2SO_4, 50% K_2O	KCl, 50% K_2O	Superphosphate, 20% P_2O_5	Hydrated lime, 94% $Ca(OH)_2$			
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
61	18	3	5	None	65	2.71	2.6
81					58	2.42	
62	18	3	None	6	52	2.16	2.1
82					50	2.10	
63	None	None	5	6	38	1.60	1.4
83					27	1.13	
64	18	3	5	6	55	2.30	2.4
84					59	2.46	
65	18	3	5	3	60	2.50	2.6
85					62	2.60	
66	18	3	5	9	58	2.42	2.4
86					57	2.38	
67	18	3	2.5	6	74	3.10	2.7
87					56	2.34	
68	18	3	7.5	6	50	2.10	2.3
88					59	2.46	
69	12	2	5	6	48	2.00	2.1
89					54	2.25	
70	24	4	5	6	49	2.04	2.0
90					49	2.04	
71	None	None	None	None	32	1.33	1.1
91					21	0.88	
72	"	"	"	6	21	0.88	0.8
92					16	0.67	
73	"	"	5	None	31	1.30	1.4
93					35	1.46	
74	18	3	None	"	50	2.10	2.1
94					52	2.16	
75	None	None	"	"	22	0.92	0.9
95					23	0.96	
Manure C	"	"	"	"	52	2.16	
" D	"	"	"	"	50	2.10	2.3
" E	"	"	"	"	60	2.50	
" F	"	"	"	"	56	2.34	

The effect of potash

Synthetic composts of spent licorice roots as shown in table III afford an excellent opportunity to test the effect of potash on the yield of mushrooms. Practically all of the potash has been washed out of the licorice roots during the hot water extraction; similarly, most of the potash is removed from the brewers' grains during the extraction of the malt. Furthermore, the spent licorice roots are ideal for plot experiments; the roots have been cut into 1- to 2-inch lengths and vary from fine threads to fibers ⅜ inch in diameter. The roots retain moisture evenly and handle easily. An eight-ton mixture of the roots and brewers' grains was prepared and composted for a month. At the end of this time the pile was divided into 16 heaps; potash, superphosphate, and lime were added to these heaps; they were then thoroughly mixed and split into two plots as shown in table V. The duplicate plots were placed on different shelves in the mushroom house.

The results of the effect of potash are shown in table V. Due to overcomposting and cooling of the compost when making up the plots, the mushroom house did not heat properly during the sweating out process. As a consequence, insect trouble was encountered and the yields were not altogether satisfactory. The effect of the addition of potash, however, is clear: by its use the yield was almost double that of plots to which only N and P_2O_5 were added. Other experiments with plots containing a ton of compost substantiate this conclusion. The effect of adding phosphates is not distinct because some three-fourths of the phosphates required were already present. Lime had no effect on the yield under the conditions of this experiment.

Composting

After all the necessary ingredients are supplied the next important step is the fermentation or "composting" of the materials. The process of composting consists in the microbial decomposition of the carbonaceous materials, in the synthesis of microbial proteins, and in the conditioning of the fibrous materials to absorb and retain moisture. Waksman and Nissen (**14**) have shown that as a result of the composting of manure there is a reduction in water-soluble substances, hemicelluloses, and to less extent in cellulose. This is accompanied by an increase in lignin, total nitrogen (which is present chiefly in the form of insoluble microbial proteins), and ash. The experiments of Waksman and Iyer (**12**) indicate that lignin and microbial proteins form complexes. It appears that the nitrogen of these ligno-protein complexes is unavailable unless the lignin is oxidized. It is assumed that the mushroom mycelium can oxidize lignin because the lignin content of the compost decreases as a result of the growth of the mycelium. The writer (**11**) has observed that the mycelium forms highly colored products when lignin, tannin, and many aromatic hydroxy and amino compounds are added to an agar medium. These colored products appear to be the result of oxidations by the mycelium. The mushroom mycelium has strong oxidizing powers which enable it to utilize the insoluble nitrogen of the ligno-protein complexes by oxidizing the relatively toxic lignin. Since the mycelium has a nitrogen source at its disposal which is unavailable to most of the microorganisms present in the compost heap, it is able to consume the carbonaceous materials not used previously.

The length of the composting period is of paramount importance, although the determination of the length is still an art. The experienced grower considers the composting sufficient when the manure has a dark color (indicating the liberation of lignins by the consumption of other constituents) and when the tensile strength of the straw in the manure is low (indicating that the straw can absorb and retain water). From the point of view of preparing synthetic composts the length of the composting period is influenced by the nature and subdivision of the fibrous material, by aeration of the compost pile, and by the use of lignin and tannin extracts. These factors will now be considered.

When the fibrous material is the same as that present in manure composts, *i.e.*, straw, then the composting period is relatively long—about 4 to 5

TABLE VI

THE EFFECT OF CHOPPING THE STRAW OF SYNTHETIC STRAW COMPOSTS ON THE YIELD OF MUSHROOMS (AS SHOWN IN TABLE III)

PLOT	LONG STRAW	CHOPPED* STRAW	BED SURFACE	MUSHROOMS PER PLOT	MUSHROOMS PER SQ. FT.	COMMERCIAL YIELD PER SQ. FT.
	lb.	*lb.*	*sq. ft.*	*lb.*	*lb.*	*lb.*
1	2000	2000	696	2484	3.57	2.7
2	2000	None	384	1273	3.32	2.5
4	250	250	48	142	2.96	2.2
4A			48	142	2.96	
5	None	500	48	98	2.04	1.7
5A			48	115	2.40	
12–2	200	250	36	96	2.67	2.1†
12–2A			45	132	2.93	
12–3	None	450	39	111	2.85	2.1†
12–3A			36	103	2.84	
12–4	450	None	50	101	2.00	1.8†
12–4A			50	138	2.76	
Check	Manure	....	3600	12003	3.33	2.5

* Straw was chopped with a hammer mill, using a one inch screen.
† These results are typical of 4 or more replications in which different nitrogen sources were used.

weeks. It is necessary to cut the straw in order to facilitate the retention of heat and moisture both during the composting period and during the "sweating out process" (**8**). Cut straw is also easier to handle; long straw binds and is laborious to turn. By subdivision of the straw the length of the composting period may be reduced. Before adding the various ingredients to the straw, its moisture content is conveniently brought up to about 50 per cent. by placing a revolving lawn sprinkler on top of the straw pile, which should be about 6 ft. high. It is sprinkled until water leaches from the pile; the watering is continued for several days. Rye and wheat straw are preferable to oat straw or corn stover since the latter have a tendency to lose their fibrous structure when the microbial decomposition has proceeded to the stage where moisture is retained well.

The effect of chopping the straw on the yield of mushrooms is shown in table VI. The results show that chopping the straw caused a reduction in the number of square feet of bed surface and also a reduction in the yield for a given quantity of straw. The reason for the plots with the entire straw chopped giving less mushrooms per plot is because all the plots were composted for an equal length of time; the plots with all chopped straw composted faster than the plots in which the straw was partially or not chopped. When the chopped straw was arranged in plots with the *same* bed surface area as the partially chopped straw (plots 4 and 5), the yield per sq. ft. of bed surface was greatly reduced. If allowance was made for the shrinkage due to the rapidity of composting (all the beds made up to a six-inch depth regardless of the resulting surface area) and if the composting period was shorter as in plots 12–2,3,4, then there is no marked difference in yield.

TABLE VII

THE EFFECT OF THE LENGTH OF COMPOSTING AND THE VENTILATION OF LICORICE ROOT COMPOST ON THE YIELD OF MUSHROOMS

PLOT	DATE OF ARRANGEMENT OF PLOT, 1938	NUMBER OF DAYS COMPOSTED	NUMBER OF TIMES COMPOST WAS TURNED	COMPOST IN PLOT WHEN ARRANGED	BED SURFACE	MUSHROOMS PER PLOT	MUSHROOMS PER SQ. FT.	COMMERCIAL YIELD PER SQ. FT.
				lb.	*sq. ft.*	*lb.*	*lb.*	*lb.*
B–1	Aug. 18	16	3	950	48	167	3.48	2.60
B–2					48	163	3.40	2.54
B–5	Aug. 25	8	2	950	48	187	3.90	2.92
B–6					48	179	3.73	2.79
B–7	Sept. 1	2	1	950	48	115	2.40	1.79
B–8					48	80	1.67	1.25
B	Aug. 17	17	3	25000*	1416	2871	2.03	1.52
2†	Oct. 26	21	3	22000*	1152	4336	3.76	2.82

* Approximately. Each of these piles is typical of 3 others prepared at the same time.

† Ventilator placed in pile at the second turning.

Even though a larger yield for a given quantity of material is obtained from composts of long straw, the best commercial practice is to cut the straw in view of the disadvantages of using long straw.

The composting period is comparatively brief when the fibrous materials are spent licorice roots or spent tannery bark, nuts, and leaves. The reason for these materials requiring less composting is that their chemical composition is more or less similar to composted manure; *i.e.*, a large percentage of lignin or tannin and cellulose, and a small amount of easily decomposable carbonaceous matter. These materials contain about 65 per cent. moisture when purchased, and have other desirable qualities already described. They make better composts than straw.

Synthetic composts prepared with spent licorice roots and composted for 15 days in 1937 gave commercial yields of 2.5 lb. per sq. ft. of bed surface, when prepared in plots of a ton or less. As a result, large piles of licorice root compost, as plot B in table VII, were prepared the next year. The yields of the large piles were unsatisfactory; however, small plots (B1 to B8, table VII) arranged at the same time to determine the length of the composting period gave good yields. It was evident, then, that the composition of the synthetic compost was satisfactory, but that the method of composting was improper. The small piles had a relatively large surface exposure and only a small "core" removed from the atmosphere, so that almost all parts of the small piles received good aeration; the reverse was the condition present in the large piles. By placing a ventilator, made of a lattice-work of

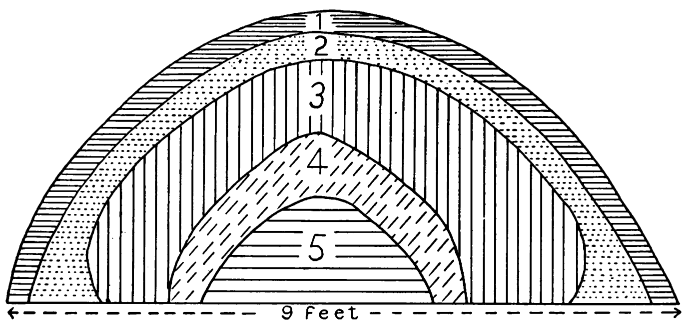

FIG. 1. Cross section of synthetic licorice root compost pile without ventilator. Measurements were made after composting 12 days, at the second turning.

ZONES	MOISTURE	pH	TEMPERATURE	SIDE OF PILE		TOP OF PILE
				CO_2	O_2	CO_2
	%		°F.	%	%	%
1. Wet-ammonia	75	8.2	120	2.5	17.4	8.0
2. Fire fang	63	7.9	140	7.8	12.1	11.0
3. Dark brown	64	8.1	165	14.1	5.8	15.5
4. Sour-green	64	5.8	160	24.3	0.2	22.0
5. Very sour-green	66	5.2	140	24.9	1.6	22.2

wood, in the center of the pile good aeration was also obtained in the large piles. The yields from the aerated piles was satisfactory as shown in plot 2, table VII. The conditions of moisture, pH, temperature, and aeration before and after placing a ventilator in the large piles is shown in figures 1 and 2. When preparing composts with straw the problem is to compress the straw as much as possible in order to prevent too much aeration from drying out and cooling the straw compost, whereas with closely packed materials like licorice roots it is necessary to make special provisions for aeration. STOLLER, SMITH, and BROWN (9) demonstrated that manure could be composted in about 7 days when good aeration was provided.

The results in table VII show that the best yields are obtained with small piles of licorice root composts by composting for 8 days. Composting twice as long reduces the yields somewhat; composting only 2 days reduces the yields drastically and encourages all kinds of mold growth. The large quantity of nitrogen used in preparing these synthetic composts necessitates a composting period of some 8 days. While 8 days of composting suffices in small piles, about 15 to 20 days are required in large piles with ventilators. It is not as simple to obtain proper mixing, watering, and aeration in large piles as it is in small ones.

Since one of the chief functions of composting is to make the nitrogen unavailable to most microorganisms by its combination with lignin, the possibility occurred of achieving this combination without the lengthy microbial decomposition. Accordingly, several nitrogen sources as shown in table

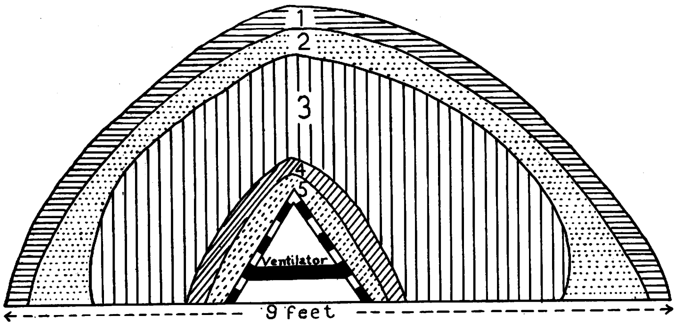

FIG. 2. Cross section of synthetic licorice root compost pile with ventilator. Measurements were made after composting 12 days, at the second turning.

ZONES	MOISTURE	pH	TEMPERATURE	SIDE OF PILE		TOP OF PILE
				CO_2	O_2	CO_2
	%		°F.	%	%	%
1. Wet-ammonia	75	8.2	120	3.5	17.5	4.5
2. Fire fang	58	7.7	140	12.0	8.3	4.0
3. Dark brown	66	8.0	160	9.0	11.1	3.0
4. Dry	66	7.7	......	4.5	15.7	1.8
5. Fire fang	63	7.9	140	2.4	18.4	0.7

VIII were soaked in solutions of lignin extracts of the paper industry and in solutions of tannin extracts. Exact details of the procedure are described elsewhere (**10**). Substances like lignin or tannin are called "coprinating" agents.

The results in table VIII show that when concentrated nitrogenous materials are soaked in solutions of lignin or tannin extracts, the outdoor composting process is unnecessary. In most cases the yields were better without than with composting when lignin or tannin was used. Some nitrogenous materials gave better yields with tannin than with lignin, and vice versa. It is interesting to note that the plots with "Uramon" (a Dupont product in which the urea is diluted to 42 per cent. N) gave a good yield of mushrooms without composting when combined with lignin and tannin.

TABLE VIII

SYNTHETIC LICORICE ROOT COMPOSTS PREPARED BY THE COMBINATION OF TANNIN OR LIGNIN WITH NITROGENOUS MATERIALS. EACH PLOT HAS A BED SURFACE OF 48 SQUARE FEET

NITROGEN SOURCES	NITROGEN PER TON OF LICORICE ROOTS	"COPRINATING" AGENT	AGENT PER TON OF LICORICE ROOTS	PLOTS COMPOSTED 30 DAYS OUT-OF-DOORS			PLOTS COMPOSTED 7 DAYS OUT-OF-DOORS			PLOTS NOT COMPOSTED OUT-OF-DOORS			
				PLOT	MUSHROOMS PER PLOT	MUSHROOMS PER SQ. FT.	PLOT	MUSHROOMS PER PLOT	MUSHROOMS PER SQ. FT.	PLOT	MUSHROOMS PER PLOT	MUSHROOMS PER SQ. FT.	COMMERCIAL YIELD PER SQ. FT.
	lb.		*lb.*		*lb.*	*lb.*		*lb.*	*lb.*		*lb.*	*lb.*	*lb.*
Soybean meal	115	Tannin	30	28	127	2.65	31	151	3.15	41	171	3.56	2.67
" "	115	Lignin	45	29	113	2.35	32	139	2.90	42	103	2.15	1.60
Dried brewers' grains	180	"	50	30	127	2.65	33	148	3.08	43	153	3.19	2.40
Brewery sludge	350	None	......	26	110	2.29	34	148	3.08	44	164	3.42	2.52
Wet brewery yeast	450	"	......	......	......	......	35	94	1.96	......	......	......	......
" " "	450	Tannin	30	......	......	......	36	146	3.04	46	159	3.31	2.50
Dried blood	60	"	25	15*	107	2.23	......	......	......	47	131	2.73	2.04
" "	60	Lignin	40	......	......	......	38	149	3.10	48	125	2.60	1.96
Uramon (42% N as urea)	18	"	47	3†	88	1.84	39	141	2.94	49	140	2.92	2.19
" " " " "	18	Tannin	30	4†	94	1.96	40	140	2.92	50	146	3.04	2.29

* No tannin in this plot.
† Composted 42 days out-of-doors.

Since urea is very toxic to the mushroom mycelium, it may be inferred that a real combination did occur between it and the lignin or tannin. The plot with yeast combined with tannin showed a much better yield than with yeast alone. The probable reason why plots with the brewery sludge alone gave a good yield is because it consists of the proteins of the malt which are precipitated by the tannins of the hops; actually, then, these plots of brewery sludge did contain tannin. Sometimes, under the conditions of indoor composting, fair yields were obtained when no lignin or tannin extracts were used. But usually such plots ammoniated strongly so that the mycelium could not grow, or molds developed and prevented the growth of the mycelium. Indoor composting of synthetic composts requires the use of substances in the *nature* of lignin or tannin and fibrous materials like spent licorice roots or spent tannery bark. The obstacle to the use of this process is that the solutions of tannin and lignin are necessarily acid; although the finished compost has a pH of 7.0 or higher the presence of acidifying substances makes such composts more susceptible to the truffle disease of the mushroom mycelium to be described later.

Preparation of the mushroom bed

In order to obtain good yields it is not only necessary to consider the composition and condition of the compost, but also the quantity used in preparing the mushroom bed. The usual commercial practice is to use about 12 bushels of compost for 24 sq. ft. of bed surface, so that the beds have a depth of about 6 inches after tamping. A licorice root compost, which is an ideal material for experimentation, as already explained, was used to prepare beds in which the number of bushels for 24 sq. ft. of bed surface was varied from 6 to 14 as shown in table IX. The results show that the yield increased in almost the same proportion as the increase in quantity of compost; the yield from 12 bushels was almost double that from 6 bushels. In another experiment the volume or depth of the bed was kept constant by diluting one-half of the root compost with an inert material like spent Quebracho wood chips; the result was that the yield was reduced to about one-half. Thus it appears that the usual commercial practice of making the beds gives the best yields.

In table IX there is shown also how the bed temperatures vary with the quantity of material present in the bed. The bed temperature may be controlled by regulating the quantity of material in the bed. It is necessary to attain temperatures of 140° F. in the beds during the "sweating out process" in order to obtain air temperatures of 125° to 130° F. in the mushroom house for the purpose of killing pests. The plots with 6 to 8 bushels per 24 sq. ft. (table IX) were free of pests because the air temperature was 125° to 130° F. since most of the beds in the mushroom house had 12 bushels, and consequently, a temperature of 140° F. It is evident, then, that about 12 bu. of compost should be used for 24 sq. ft. of bed surface, not only to obtain the best yields but also to obtain the high temperatures necessary for killing pests.

TABLE IX

THE EFFECT OF QUANTITY OF SYNTHETIC LICORICE ROOT COMPOST PER SQUARE FOOT OF BED SURFACE ON THE TEMPERATURE DURING THE "SWEATING OUT PROCESS" AND ON THE YIELD OF MUSHROOMS

Plot	Temperatures of "sweating out process"		Size of plot	Bushels† for 24 sq. ft.	Compost used when filling beds, 66% moisture		Mushrooms from 24 sq. ft.	Mushrooms per sq. ft.‡	Dry wt. basis		Commercial yield per sq. ft.
	Highest temp. attained	Av. temp. during 72 hrs. of peak heat*			In 24 sq. ft.	Per sq. ft.			Compost per sq. ft.	Mushrooms per sq. ft.	
	° *F.*	° *F.*	*sq. ft.*	*bu.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
1	130	126	24	6	252	10.5	41	1.67	3.57	0.167	1.25
5	133	129					39				
2	135	130	24	8	336	14.0	55	2.23	4.76	0.223	1.65
6	133	130					52				
3	141	137	24	10	420	17.5	58	2.42	5.95	0.242	1.80
7	139	136					58				
4	145	140	24	12	504	21.0	77	3.20	7.14	0.320	2.40
8	145	141					76				
9	148	146	24	14	588	24.5	82	3.42	8.33	0.342	2.55
Bed 8	....	....	312	8	(336)	(14.0)	53	2.20	(4.76)	0.220	1.65
Pile 5	146	139	1392	12	(504)	(21.0)	78	3.23	(7.14)	0.323	2.40

* Average of six successive readings at 12-hour intervals.
† The average bushel weighed 42 lb.
‡ Average.

pH of the compost and the control of weed and disease fungi

The optimum pH for the growth of the mushroom mycelium is 6.5 to 7.0; this pH range, however, is very suitable for other fungi so that the pH of the compost must be adjusted to prevent weed and disease fungi. The common green molds which are omnipresent on spoiled food, and which have spores that are resistant to high temperatures, are easily prevented from growing on the compost by maintaining the pH above 7.0. The many fungi that can grow on composted manure or synthetic composts when the pH is above 7.0 are all eliminated by the high temperatures attained during the "sweating out process" with the exception of two: Coprinus sp. (chiefly *Coprinus fimetarius*) and *Pseudobalsamia microspora.*

The conditions are ideal for Coprinus sp. when there are sufficient alkaline minerals in the compost to cause a small liberation of ammonia from an abundant supply of nitrogenous matter in the compost and, as a consequence, the pH is 8.0 to 9.0. Ammoniating salts and urea are not as toxic to it as to the mushroom mycelium. The addition of one liter of 50 per cent. ammonium hydroxide to 5 sq. ft. of bed surface during the "sweating out process" encouraged the growth of Coprinus sp., whereas even 10 per cent. NH_4OH prevented the growth of the mushroom mycelium, though there was little change in pH. The control of Coprinus sp. would be achieved by acidifying the compost to pH 7.0–7.5, if this procedure were not favorable to the other heat resistant fungus—*P. microspora.*

Since very little is known about *P. microspora,* which causes the truffle disease of the mushroom mycelium, it is necessary to discuss it in some detail. *P. microspora* cannot grow on a *non-sterile* manure or synthetic compost, even if the compost is acidified so that the pH is reduced to 6.0. It can grow only in the presence of or, more likely, on the mushroom mycelium. The writer (**11**) has shown that it is one of the few fungi which can produce volatile sulphides. It seems that with the implement of these sulphides this fungus can attack the mushroom mycelium. A quinone-like substance continually volatilizes from the surface of the mushroom mycelium as a result of its intense oxidizing activity; this volatile substance acts as a barrier to all organisms, except insects and *P. microspora,* that attack the mushroon mycelium (**11**). The sulphides of *P. microspora* enable it to reduce the quinones so that it can attack, or at least grow in the presence of, the mushroom mycelium. The reducing ability of *P. microspora* may be demonstrated when a chemical like alpha naphthol is added to an agar medium and inoculated first with the mushroom mycelium, which causes the agar to be colored purple, and then inoculated with *P. microspora,* which then decolorizes the agar.

The growth of *P. microspora* on the mushroom mycelium is expedited by the presence of acidifying substances and sulphur compounds in the compost, even though the overall pH may be 8.0. The mushroom mycelium produces acids which reduce the initial pH 8.0–8.5 of the compost to 6.0–7.0. It is possible that the presence of acidifying materials in the compost assists the evolution of sulphides by *P. microspora* after the pH of the compost has been reduced by the mushroom mycelium. It has been observed that the addition of acidifying substances like mineral acids, gypsum, superhosphate, tannic acid, etc., to the compost permits the rapid growth of *P. microspora* on the ensuing mushroom mycelium. When acidifying substances are absent and when the compost is properly buffered with alkaline salts, the mycelium of *P. microspora* is greatly retarded in its growth on the mushroom mycelium and the spores of this organism usually fail to germinate.

The large volatilization of ammonia during the "sweating out process" appears to be an important factor for killing spores of *P. microspora*. The presence of alkaline salts in the compost favors a greater evolution of ammonia. In the attempt by the writer to kill the spores of this fungus by numerous fumigants, such as sulphur dioxide, formaldehyde, chloropicrin, dichloronitroethane, carbon disulphide, etc., only ammonia was found of value. It is necessary, therefore, to prepare synthetic composts with somewhat more nitrogen than is necessary to produce the largest yields in order to insure a sufficient volatilization of ammonia. It is also necessary to add sufficient alkaline salts and adjust the pH at 8.0 to 8.5, not only to assist the evolution of ammonia, but also to build up a high buffering capacity of the compost for reasons previously described. This condition of the compost, however, is highly favorable to the Coprinus sp. It is thus essential to strike a balance: make the conditions in the compost somewhat more favorable to Coprinus than to *P. microspora,* since the former is less dangerous to the mushroom crop. The mushroom mycelium can ultimately grow over the mycelial growth of the Coprinus sp. that preceded it; but when *P. microspora* follows the growth of the mushroom mycelium, the crop is greatly reduced or lost.

Summary

A method is described for preparing synthetic compost for mushroom culture from various source materials of N–P–K to produce about 13 lb. N, 4 lb. P_2O_5, and 10 lb. K_2O in a ton of fibrous material having 70 per cent. moisture, after allowing for the quantities of these three constituents present in the fibrous material. Several thousand tons of synthetic composts have been prepared by this method; it has been tested over a period of 5 years; and the yield has been as good as or better than that from horse manure composts.

One of the chief inadequacies of previous attempts to prepare satisfactory composts or "artificial manures" has been the omission of potash. By the addition of K_2O to synthetic composts prepared from spent licorice roots and brewers' grains, the yield was almost double that of similar composts to which only N and P_2O_5 were added.

The effect of potash, various sources of nitrogen, the subdivision and the character of the fibrous materials, the duration of and conditions for composting, the quantity of compost in the mushroom bed, and the relation of pH to the control of weed and disease fungi on the yield of mushrooms is reported.

A process is described in which tannin and lignin extracts are combined

with nitrogenous materials in order to avoid the lengthy outdoor composting period and to produce greater yields of mushrooms.

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L. F. LAMBERT MUSHROOM SPAWN AND PRODUCTS
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